SAFETY AND ECONOMIC BENEFITS OF PARTIALLY PAVED SHOULDERS

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ABSTRACT

The main function of partially paved shoulders (PPSs) is to improve safety and reduce maintenance. As well, any tendency to edge cracking is moved from the travel lane to the partially paved shoulder, thereby extending pavement life. Safety is improved by minimizing pavement edge drop off and reducing granular maintenance. Property damage is also reduced and driver comfort increases because of a perceived increase in road width.

This paper is based on a study of 180 PPS sections, and is directed toward quantifying the safety and economic benefits. Motivation for the study came from a climate of economic restrictions and the associated need to quantify any benefits of PPS's. Survey and evaluation procedures are described in the paper, as is the innovative life-cycle cost approach. Based on the survey, the majority of people did not feel that gravel shoulders were safe and found them to be a dramatic exit from the roadway. Gravel fly up was identified to be a major concern and 80% of those surveyed had experienced broken or cracked windshields while 73% had experienced paint chips and 8% had encountered broken headlights due to gravel fly up.

The results show that PPS's have definite safety benefits; moreover, granular PPS's had a significantly longer service life than earth PPS's. Performance equations and life-cycle costs which quantify these results are provided. Finally the paper presents conclusions and recommendations toward those situations where partially paved shoulders are warranted for safety and economic reasons.

INTRODUCTION

Highway shoulders can be earth, granular, partially paved and fully paved. The Ontario Ministry of Transportation's (MTO) current design standards state that all four lane divided highways be constructed with full width granular shoulders with a 0.5 m portion partially paved [1]. The main function of the partially paved shoulder (PPS) is to improve safety and reduce maintenance. Safety is improved by minimizing pavement edge drop-off, increasing driver comfort and reducing property damage. Associated maintenance is also reduced in addition to increasing pavement life by reducing the cracking at the edge of pavement [2]. The overall standard was deemed to be a cost effective means of improving safety and reducing maintenance costs by reducing the rate of shoulder gravel loss adjacent to the edge of pavement [1].

With economic restrictions and an increasing need to examine current policies, a study [Tighe 96] was undertaken to reassess the performance of PPSs within the southwestern region. The original data base from a preliminary study [3] was updated and expanded to develop relationships between PPS performance, age, crossfall and shoulder type. This paper provides findings from the 1996 study in addition to providing an economic analysis and quantifies the safety benefits based on a survey.

BACKGROUND

The Ontario Geometric Design Manual [4] states that highway shoulders are provided adjacent to the roadway to provide refuge for stopped or disabled vehicles, for travel by emergency vehicles and for lateral support of the roadway structure. According to C-SHRP [5], the following are fundamental shoulder characteristics:

1. The shoulder must be strong enough to support vehicles under all weather conditions.

2. The shoulder material must be able to withstand sudden braking and turning movements due to vehicles which swerve off the road at high speed and attempt to move back on the travelled way.

3. The shoulder surface should always be level with the top of the pavement to permit safe deceleration to a stop, i.e., no edge ravelling or rutting.

4. The shoulder must be wide enough to keep a vehicle from striking roadside hazards.

5. The shoulder geometry should be such that normal traffic and vehicle speeds are not reduced by a vehicle that is temporarily stopped on the shoulder.

6. A textural difference (i.e., rumble strips) between the shoulder material and roadway is desirable to instantly warn drivers when their wheels leave the pavement.

While it is generally agreed that these basic characteristics must be present along highways, there are wide variations based on the functional classifications of the roadway.

CONDITION RATING SCHEME

To assess the PPS, a condition rating was required. The condition rating is a modified version of the existing paved shoulder rating system described in the Manual for Condition Rating of Flexible Pavements [6]. The modified system used [2] identifies the distresses and incorporates three levels of severity and density as shown in Figure 1. The identified distresses include: cracking, separation, distortion, breakup and edge break. Severity is described as i) slight, ii) moderate, or iii) severe. Levels of density are i) intermittent, < 20%, ii) frequent, 20-50%, and iii) extensive, > 50% [2].

DISTRESS MANIFESTATION INDEX

The Distress Manifestation Index (DMI) combines the density and severity of all distresses. This quantitative measurement is calculated using equation 1, where the W_i is summation of the weighting of the individual distresses:

$$DMI = \sum_{i=1}^{5} W_i \qquad (1)$$

Figure 2 shows the weighting of the respective distresses. Higher DMIs are indicative of poorer PPS performance [2]. The weighting system used to assess PPSs is similar to the flexible pavement system with the addition of breakup and edge break [6]. Each of the five distresses was weighted according to relative influence on performance. Breakup was assigned the highest relative weighting based on its severe impact on the PPS performance. The other distresses were weighted based on their anticipated effect on PPS function and performance. The sum of the weighting for each section were determined and then used as a basis of assessment.

PERFORMANCE CATEGORIES

The four categories associated with DMI ranges to assess PPS performance are listed below with sample typical distresses [2].

Excellent (DMI < 7.5)
Slight extensive, or moderate intermittent cracking is generally the only distress.

Good (7.5 < DMI < 17.5)
Typically exhibits two to three of the following distresses: moderate, frequent to extensive cracking; slight, intermittent to frequent separation and/or slight to moderate, intermittent edge break.

Fair (17.5 < DMI < 27.5)
Usually shows the following four distresses: severe, frequent to extensive cracking; slight, intermittent to extensive separation; slight intermittent breakup; slight to moderate and/or intermittent edge break.

Poor (DMI > 27.5)
Generally exhibits all of the five distress types: severe extensive cracking; slight to moderate, extensive separation; severe, intermittent to frequent breakup; moderate to severe, frequent edge break and/or severe intermittent distortion.

GUIDE FOR DESCRIBING DENSITY

DESCRIPTION	% OF LENGTH
INTERMITTENT	< 20%
FREQUENT	20-50%
EXTENSIVE	> 50%

GUIDE FOR DESCRIBING SEVERITY

TYPE OF DISTRESS	SEVERITY		
	SLIGHT	MODERATE	SEVERE
Cracking	Single crack	Progressive multiple cracks beginning	Progressive multiple cracks and alligator
Separation	single < 12 mm	single 12-19 mm	single or multiple cracks > 19 mm
Break-up	Alligator pattern established with spalling of blocks	Disintegration with small potholes up to 150 mm	Disintegration with potholes > 150 mm
Edge Break	Edge cracked with no loss of material	Edge break with some loss of material	Edge break with substantial material loss
Distortion		Noticeable edge curling, depression, heaving No major cracks	Obvious edge curling, depression, heaving, with multiple cracks

Figure 1/ Guidelines for PPS Distresses [2]

DISTRESS	SEVERITY			DENSITY		
	SLIGHT	MODERATE	SEVERE	INT. < 20%	FREQUENT 20-50%	EXTENSIVE > 50%
CRACKING	1.5	3.0	4.5	1.5	3.0	4.5
SEPARATION	1.0	2.0	3.0	1.0	2.0	3.0
BREAK-UP	6.0	7.5	9.0	1.5	3.0	4.5
EDGE BREAK	1.5	3.0	4.5	1.5	3.0	4.5
DISTORTION		3.0	4.5	1.5	3.0	4.5

Install Equation Editor and double-click here to view equation.

DMI is distress manifestation index, and

W_i = *individual weightings*

Figure 2/ Partially Paved Shoulder Condition Weightings [2]

DATA COLLECTION

The existing data file from the preliminary study [3] and the Ontario Pavement Management System Inventory were used to identify PPS sections for evaluation [2]. PPS sections were organized according to Highway and District. Other information pertinent to the study included location, length, year of construction, type of shoulder and thickness.

Figure 3 is the form used to evaluate the PPS sections. Distress manifestations in each PPS section were recorded on the evaluation form. PPS crossfalls for each section were measured in six areas. An average crossfall was calculated and used in this analysis. In total, 182 flexible pavement sections with 0.5 m PPS's were evaluated [2].

DATA ANALYSIS

The majority of PPSs examined were constructed with one lift asphalt and paved integrally with the surface course. This section details shoulder type, rate of deterioration, crossfall, construction, other observations and functional assessment. Based on limited data, a comparison of one and two lift PPSs was not possible. Additionally a comprehensive assessment on pavement edge cracking with PPSs was not possible as non PPS sections of similar age and attributes would have to be evaluated. However, PPSs that were constructed integrally with the surface coarse showed better performance than those that were retrofitted as pavement edge cracking was more prevalent with the retrofits.

Shoulder Type

The PPS sections were separated into those built directly on subgrade and those built on granular. Figure 4 demonstrates a relationship between DMI and Age for PPSs built directly on subgrade. The scatter plot indicates that as the PPS ages, the DMI increases. The initial regression analysis had a considerably low coefficient of determination. When the individual PPS sections were examined, those PPSs built on sandy subsoils had consistently better performance than those built on silty/clayey subsoils. In order to develop a more typical performance of earth PPSs, those sections on known sandy subsoils (which act similar to granular PPSs) were removed from the data set. The coefficient of determination was determined to be .64 and Equation 2 was developed. In addition, an outlier test was performed and any outliers were removed.

$$\mathbf{DMI_{EARTH} = 1.42Age + 6.99} \qquad \mathbf{(2)}$$

This relationship between DMI and Age was also developed for the granular shoulders. Figure 5 depicts the performance expected performance of Granular shoulders. Regression analysis was used to develop Equation 3 which explains the relationship between DMI and Age for granular sections. The coefficient of determination was calculated to be .62.

$$\mathbf{DMI_{GRANULAR} = 1.09Age + 4.22} \qquad \mathbf{(3)}$$

Using Equation 2, Table 1 was developed. These values can be used as a guideline for expected PPS performance on subgrade. Actual PPSs built on subgrade can be compared to values in Table 1 to determine how they are performing relative to anticipated performance. Table 2 shows the expected

LOCATION FROM	TO	
HIGHWAY	CONTRACT	DISTRICT
LENGTH km	CODES	SURVEY DATE

DISTRESS	**SEVERITY**			**DENSITY**		
	SLIGHT	MODERATE	SEVERE	INT. < 20%	FREQUENT 20-50%	EXTENSIVE > 50%
CRACKING						
SEPARATION						
ALLIGATOR						
BREAK-UP						
EDGE BREAK						
DISTORTION						

CHECK TYPE OF PPS CONSTRUCTION DEPTH OF PPS __________mm

PPS INTEGRAL o PPS RETROFITTED o EARTH SHOULDER o GRAVEL SHOULDER o

MAINTENANCE TREATMENT ______________________________

REMARKS ______________________________

____

____

EVALUATED BY ______________________________

Figure 3/ Partially Paved Shoulder Condition Evaluation Form [2] performance for PPSs built on granular. Table 2, similar to Table 1 for PPSs constructed directly on subgrade can be used as a guideline in predicting PPS performance on granular.

The low coefficients of determination for both equations 2 and 3 can be explained by the fact that there are many factors affecting the performance. It is also important to note that both the constant and the slope of the line for granular shoulders are lower than for the earth shoulder equation. This indicates that PPSs built on granular shoulders perform better than those built on subgrade. These models can be used by designers and maintenance staff to identify those sections which are performing below expected performance levels (ie. identify which PPSs may not perform their intended function for the service life of the pavement).

Table 1/ Expected PPS on Subgrade Performance

AGE	Expected DMI	Performance Rating
0-1	7.5	Excellent
1 - 7 years	7.5-17.5	Good
8 - 15 years	17.5-27.5	Fair
16+	> 27.5	Poor

Table 2/ Expected PPS on Granular Performance

AGE	Expected DMI	Performance Rating
0-2	7.5	Excellent
2-12 years	7.5-17.5	Good
13-21 years	17.5-27.5	Fair
22+	> 27.5	Poor

Overall the PPS minimizes pavement edge drop-off and reduces granular maintenance. Property damage is also reduced and driver comfort increases by the increased road width. The subjective observations made by the evaluators indicated that when the PPS is performing in the fair or better categories, it performs its function. Even though distresses can occur at various densities and severities, the overall PPS still reduces pavement edge drop off, gravel damage and also increases driver comfort. The exception was when breakup occurred. If this distress occurred in a section, the PPS became a maintenance problem and acted similar to a granular shoulder. In these instances, the PPS would require repair in order to adequately perform its function [2].

Crossfall and Performance

Six crossfall measurements for each section were arbitrarily taken and averaged to estimate the crossfall of each PPS. Current MTO standards call for 6% PPS crossfall. Crossfall averages for each District in Southwestern Region are shown in Table 3. The results show that the 6% standard is not being achieved. It is important to note that both studies have assessed PPSs during the winter and this may mean that the crossfalls were lower and what they would be in non winter season.

Table 3/ District Analysis of Crossfall

DISTRICT	**Earth X-Fall (%)**	**Granular X-Fall (%)**	**Overall X-Fall (%)**
1	3.41	3.41	3.39
2	2.63	2.49	2.53
3	3.5	4.07	4
5	3.56	3.8	3.77

Figure 6 shows that the average rate of deterioration changes slightly with % crossfall. None of the earth shoulder sections met the 6% crossfall and the lowest rate of deterioration is shown to be at an average crossfall of 2% and 2.3%. However, those PPSs with crossfalls between 3% and 5% are also shown to perform well. The highest rate of deterioration is noted at 2.5% crossfall.

Figure 7 indicates that as the % crossfall increases the average rate of deterioration decreases. Those PPSs below 2.5% crossfall are showing lower levels of performance. This higher rate of deterioration can be attributed to poor drainage. The lowest rates of deterioration are shown to be at 4.2% and 6.4%. However, when the % crossfall is above 4%, the PPSs have lower rates of deterioration. It should be noted that the granular PPSs with a % crossfall of 8.0 exhibited higher deterioration rates. These PPSs were susceptible to premature edge break, break up and separation.

The following observations were made with reference to PPS crossfall. The averages consistently indicate that the PPSs are not being placed at 6% as specified. PPSs with 0-3% crossfall prematurely deteriorate compared to those PPSs with crossfalls greater than 4%. Those sections that break up prematurely exhibit crossfalls consistently below 2%. The majority of PPSs with crossfalls at 4% to 6% were performing in the fair and good categories.

While performing the evaluations, isolated deterioration was observed. This generally occurred at the low side of superelevated curves, transition point treatments, and cut sections. Poor drainage causes the premature deterioration in these areas.

Safety Assessment

To assess whether the PPS was performing its function, to improve safety and reduce maintenance, a mini survey was conducted to identify the relative benefits of PPS's for various classes of highways and traffic volumes. A total of forty people were surveyed. The completed surveys were separated into two groups whereby half of those surveyed were identified as technical people (including civil engineers and technicians) and non technical people which represent the general public. Table 4 summarizes general opinions regarding the use of shoulders and in their experiences with damage due to gravel.

Table 4/ General Survey Results

Characteristic	General Public (Yes)	Technical (Yes)	Combined (Yes)
Do you feel safer with a wider shoulder?	100%	100%	100%
Do you feel safer with a PPS?	75 %	85%	80%
Do you feel safer with a Fully Paved Shoulder?	90%	85%	88%
Have you ever encountered gravel flying up?	95%	100%	98%
Has gravel ever damaged your vehicle?	85%	90%	88%
Have you encountered broken/cracked windshields?	80%	80%	80%
Have you encountered paint chips?	60%	85%	73%

As noted in Table 4 those surveyed felt that the type of shoulder greatly influenced safety. Both groups tended to believe that a fully paved shoulder was most desirable however, they did recognize that based on the economics, they would settle for a partially paved shoulder. The majority of people did not feel that gravel shoulders were safe as they found them to be a dramatic exit from the roadway and felt they had less control in mechanical/accident type situations. In addition, it was felt that the safety was greatly dependent on the grading of the ditches and the side cuts. Based on these findings, damage due to gravel affected the vast majority of those surveyed. As noted, 80% of the people surveyed had experienced a broken or cracked windshield due to shoulder gravel flying up and 73% had paint chips due to shoulder gravel. In addition 8% of those surveyed had encountered a broken headlight due to gravel flying up from the shoulders.

Table 5 summarizes how people view the various safety factors with respect to shoulders. In each case, the surveyors were asked to select one of the following: very important, important, somewhat

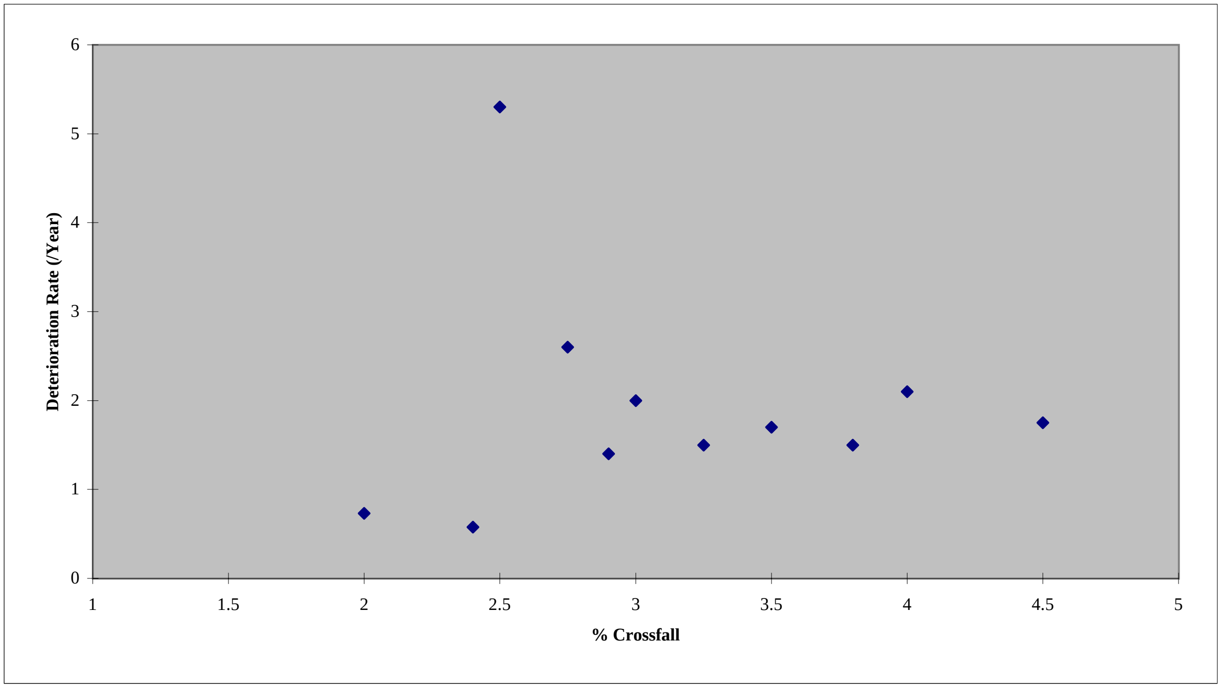

Figure 6/ Effect of Crossfall on PPSs Constructed on Subgrade

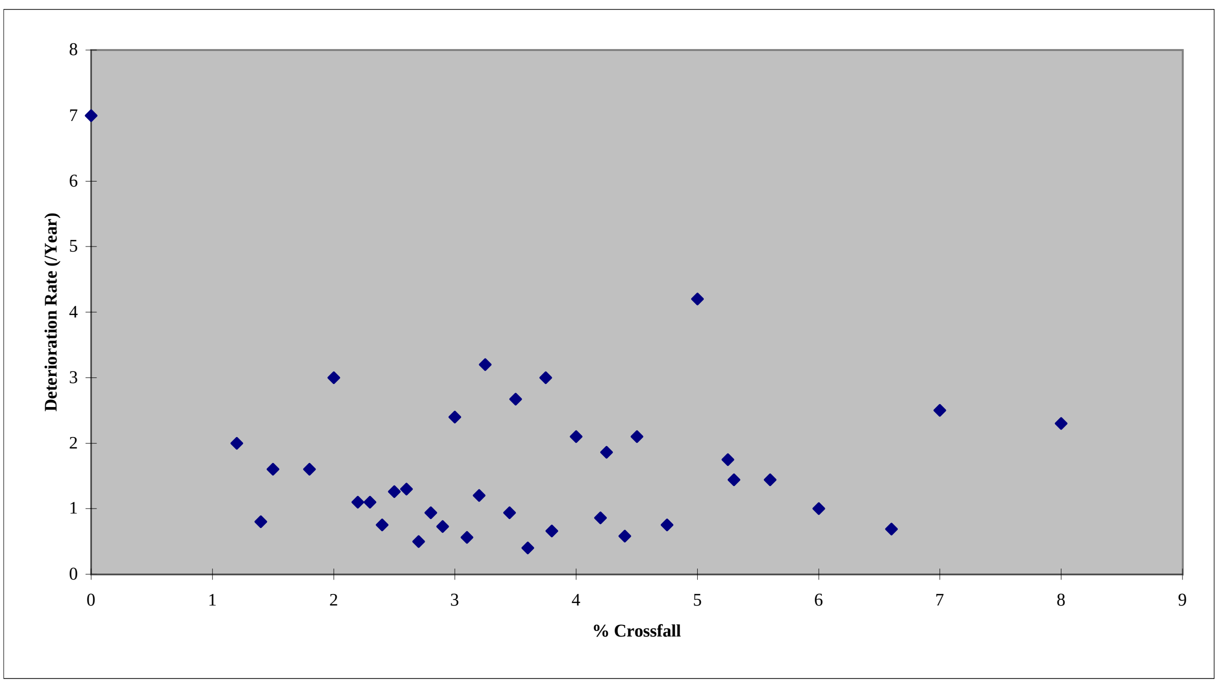

Figure 7/ Effect of Crossfall on PPSs Constructed on Granular

important and not important. The survey results were combined as they were the same for both the general public and technical people.

Based on the results, safety was perceived to be most important (very important) on freeways. On arterial facilities, all of the safety factors were deemed to be important and on collector/local roads, the factors were deemed to be important and somewhat important.

Cost Assessment

Construction costs for this analysis were based on current contract construction costs. The construction cost of the PPS was calculated assuming it was paved integrally with the surface course. Two typical prices were calculated. The PPS that was constructed on subgrade was determined to

Table 5/ Summary of Combined Survey Results

Safety Factor	Freeway	Arterial	Collector/Local
Increased Safety	Very Important	Important	Important
Reduced Pavement Drop Off	Very Important	Important	Important
Reduced Gravel Damage	Very Important	Important	Important
Increased Driver Comfort	Very Important	Important	Somewhat Important
Increased Pavement Life	Important	Important	Somewhat Important
Reduced Edge Cracking	Important	Important	Somewhat Important
Reduced Maintenance	Important	Important	Somewhat Important

be $4070/km for a 0.5 m wide and 40 mm thick PPS. The PPS that was constructed on 150 mm of Granular A was determined to be $6820/km. Shoulder related maintenance activities were extracted from the Ontario Maintenance Management System [1]. Based on the costs detailed between 1991 and 1993, and using an inflation rate to determine the 1998 costs, the cost savings for a PPS versus a granular shoulder were determined to be $145.15 /km for those PPSs constructed on subgrade and $245.15 /km for those PPSs constructed on granular. The cost savings were higher for those PPSs constructed on granular based on reduced grading.

To assess the cost effectiveness of the shoulders the present worth maintenance savings costs were calculated in present worth dollars for the respective service life of the PPS (16 years for PPSs on subgrade and 22 years for PPSs on granular). As demonstrated in Table 6, the present worth cost is calculated by subtracting the maintenance cost savings from the construction costs. The annual cost is calculated to be $160.21 /year/km for PPSs constructed on subgrade and $156.24 /year/km for those constructed on granular. The difference between the two costs is $3.97 /year/km.

Table 6/ Cost Assessment

Shoulder Type	Construction Cost	Maintenance Savings (PW)	Overall Cost (C - MS)	Annual Cost	Service Life
Granular	$ 2750		$ 2750		
PPS on subgrade	$ 4070	($ 1506.61)	$ 2563.39	$ 160.21	16
PPS on granular	$ 6820	($ 3382.74)	$ 3437.26	$ 156.24	22

The total extent (length) of the network in Ontario is divided into a provincial road network (25, 245 km 2 lane equivalent) and a municipal network (142, 685 km 2 lane equivalent) [7]. It is estimated that 73, 940 km (2 lane equivalent) would be candidates for PPSs in Ontario (very conservative estimate). Based on the approximated extent and the cost savings calculated in Table 6, the overall cost savings of using PPSs built on granular as opposed to PPSs built on earth would be $293,544/year. Nationally this total savings across the country would be $880, 630/year.

CONCLUSIONS

Overall, PPSs minimize pavement edge drop off and reduce granular maintenance. Property damage is also reduced and driver comfort increases with the increased road width. Based on the performance analysis, those PPSs which were classified in the fair or better categories were shown to be performing their function. However, if breakup occurred, they became a maintenance problem and maintenance requirements were then similar to granular shoulders.

PPSs constructed on granular shoulders were shown to have longer service lives than those shoulders constructed on subgrade. The expected service life of the PPS built on granular was 22 years while the PPSs built on subgrade was determined to be 16 years. In general, the results also indicated that the standard six percent crossfall was not being achieved. Most PPSs were constructed between two and three percent crossfall.

Based on the survey, the majority of people did not feel that gravel shoulders were safe and found them to be a dramatic exit from the roadway especially in maintenance/accident situations. Gravel fly up was a major issue as 80% of those surveyed had experienced cracked/broken windshields, 73% had encountered paint chips and 8% had encountered broken headlights due to gravel flying up from the shoulder.

PPSs constructed on granular resulted in lower annual present worth cost as compared to those PPSs constructed on subgrade. The cost assessment determined that the PPSs constructed on granular was determined to be $160.21/km while the annual cost of the PPS built on subgrade was determined to be $156.24. If this value is expanded to the Ontario road network, it implies that PPSs that are constructed on granular as opposed to earth subgrade would result in a cost savings of $293,544/year. Nationally this value would be approximated to be $880,630/year.

RECOMMENDATIONS

Based on the results presented in this study, the following are recommended:

1) PPSs should be constructed on granular materials and paved integrally with the surface coarse.

2) PPSs should be constructed on roadways where granular fly up is a serious issue, particularly on facilities which carry truck traffic.

3) For optimum performance, PPSs should be constructed with a crossfall of 4 - 6 %.

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